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PCB CONTAMINATION AND EFFECTS ON BENTHIC INVERTEBRATE COMMUNITIES AT THE *IRVING WHALE* SALVAGE SITE

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PCB Contamination and Effects on Benthic Invertebrate Communities at the *Irving Whale* Salvage Site

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ABSTRACT

In June of 1998 and 1999, two and three years after the raising of the *Irving Whale*, sediment sampling was conducted at the site where the barge was recovered to determine the extent and distribution patterns of polychlorinated biphenyl (PCB) contamination. In addition, snow crab tissue sampling, toxicity testing of sediments as well as analysis of the integrity of benthic biological communities was conducted around the *Irving Whale* footprint.

In 1998, an analysis of the PCB content of sediments revealed an area of 664 m^2 with PCB concentrations in excess of 1000 µg/g. While that represented an approximate 50% decrease in the area of high contamination over a one year period, the area of lower contaminated sediments (0.01 - 0.1 µg/g) doubled. That dispersion pattern continued in 1999 and there was no longer any area contaminated above 1000 µg/g while the lower contaminated area again doubled.

The concentrations of PCBs in digestive glands of snow crab (*Chionoecetes opilio*) continued to decline from 1996 values (0.16 - 27.20 µg/g wet wt.) to 1999 (0.085 - 0.580 µg/g wet wt.). All the 1998 and 1999 samples were substantially below Canadian health consumption limit of 2 µg/g.

Toxicity of sediments was measured in 1998 using the amphipod *Amphiporeia virginiana* and the bacterium *Vibrio fischeri* in sediment toxicity bioassays. In 10 day tests, only those sediments that had in excess of 1.5 µg/g PCB demonstrated any toxic effect on *Amphiporeia virginiana*. All of the samples taken in the vicinity of the Irving Whale footprint produced a light to moderate toxic effect to *Vibrio fischeri*.

In the vicinity of the *Irving Whale* footprint a healthy benthic community was observed. There were slight differences in the invertebrate community structure of samples taken in the vicinity of the footprint compared with the more distant sites and community structure appears to be as strongly correlated to physical characteristics of the sediment as to PCB concentration.

RÉSUMÉ

En juin 1998 et 1999, deux et trois ans après le renflouage de l'*Irving Whale*, nous avons effectué des campagnes d'échantillonnage sur le site du naufrage pour déterminer l'ampleur et le régime de dispersion des sédiments contaminés par les biphényles polychlorés (BPC). Nous avons également prélevé des échantillons de chair et de glandes digestives de crabes des neiges, mesuré la toxicité des sédiments et analysé l'intégrité des communautés benthiques au voisinage de l'empreinte de la barge.

En 1998, l'analyse de la teneur en BPC des sédiments a révélé qu'une superficie de fond de 664 m^2 présentait des concentrations de BPC dépassant 1000 µg/g. Toutefois, la superficie de la zone de sédiments plus faiblement contaminés (0,01 - 0,1 µg/g) avait apparemment doublée par rapport aux résultats de l'année précédente. Ce patron s'est répété en 1999: il ne restait plus de zone à contamination supérieure à 1000 µg/g et la superficie des sédiments moins contaminés avait encore doublée.

Les concentrations de BPC dans les glandes digestives de crabes des neiges (*Chionoecetes opilio*) mâles ont continué à baisser par rapport au niveau de 1996 (0,16-27,20 µg/g, poids humide) pour atteindre en 1999 le niveau de 0,085-0,580 µg/g. Tous les échantillons de 1998 et 1999 présentaient des teneurs nettement inférieures à la limite canadienne admissible pour la consommation humaine, fixée à 2 µg/g.

Pour mesurer la toxicité des sédiments, nous avons eu recours à des bioessais sur l'amphipode *Amphiporeia virginiana* et sur la bactérie *Vibrio fischeri* (Microtox®). Après des tests d'une durée de 10 jours, seuls les sédiments présentant plus de 1,5 µg/g de BPC ont démontré un effet toxique sur *Amphiporeia virginiana*. Tous les échantillons prélevés sur le site avaient un effet légèrement à modérément toxique sur *Vibrio fischeri*.

L'échantillonnage des invertébrés benthiques aux alentours de l'empreinte de l'*Irving Whale* a indiqué que les communautés benthiques sont en bonne santé et ne révèle aucune perturbation importante. Il semble y avoir certaines légères différences dans la structure des communautés benthiques selon que les échantillons ont été prélevés à proximité de l'empreinte de la barge ou à des sites éloignés. Ces différences sont jugées minimes, et semblent aussi fortement reliées aux caractéristiques physiques des sédiments qu'à la concentration de BPC .

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INTRODUCTION

The oil barge *Irving Whale* sank in the Gulf of St. Lawrence in 1970 and was recovered on July 30, 1996. At the time of the lift it was known that some PCBs had spilled from the heating system of the barge either at or subsequent to the sinking. Sediment remediation efforts associated with the lift operation recovered 220 kg of PCB. An estimated 150 kg remained in the sediment at the site. In addition, about 5,500 kg of unaccounted and/or non-recoverable PCBs had been lost to the environment (Gilbert *et al.* 1998).

In May-June 1996, August and October 1996 and in May-June 1997, Environment Canada and Fisheries and Oceans Canada conducted a survey of sediment and snow crab (*Chionoecetes opilio*) at and around the *Irving Whale* footprint to determine the extent of PCB contamination. Snow crab is the major commercial fishing species in the vicinity of the recovery site. The results of those investigations indicated a general decrease in the maximum concentrations of PCBs from 1996 to 1997, both in sediments and snow crab. This was attributed to physical dispersion as there was a general increase in area of lower level contaminated sediments (Government of Canada 1997; Gilbert *et al.* 1998).

In order to assist with decisions on potential remedial action at the site, additional sediment sampling was conducted in June 1998 to verify the observed pattern of dispersion of PCB-contaminated sediments. The 1998 sampling also included snow crab tissue analysis, sediment toxicity tests and assessment of benthic communities.

In March 1998, Environment Canada, in consultation with Fisheries and Oceans Canada, other government departments, and the Public Advisory Committees (PACs) established on Prince Edward Island and the Magdalene Islands, commissioned an independent review of available data for identification of potential sediment remediation options for the site. The study evaluated technical merits, limitations, costs, and the environmental health risks and benefits of each option. It included an extensive review of scientific literature and the results of testing of both sediments and snow crab that had been conducted to that date (Jacques Whitford Environment Ltd. 1998).

Based on the findings of the remediation options study, and in consultation with the PACs, the Ministers of Environment and Fisheries and Oceans decided in the spring of 1999 not to undertake further remediation at the site. This was one of the three options considered in the Jacques Whitford and Associates report and was to include further monitoring at the site.

Following the Ministers' decision, further sampling of both sediments and snow crab was conducted in the spring of 1999. This report provides a summary of the results of that sampling as well as previously unpublished data from the sampling conducted in 1998.

METHODS

Sediment Sample Collection and Analysis

The sediment sampling in 1996 and 1997 was conducted with a small manned submarine, using a reasonably precise locating method employing sonar (range) and compass (direction) positioning relative to markers on the sea floor that had been deployed to differential geo positioning system (DGPS) located positions. Since that equipment was unavailable in 1998 and 1999, sampling was conducted from a ship using a large IKU dredge to which a hydroacoustic transponder was mounted. The signal from the transponder was recorded by a transducer that was positioned 1.5 m below the ship's keel on a rail-mounted pipe. A Tracpoint II Plus positioning system that received input from the vessel's gyro and DGPS was used to record the relative position of the vessel and the dredge at the point of sampling using Hypack Navigation Software. In 1998, the error in sampling positioning for such a method was estimated to be $\pm$ 0.5 m from recorded positions. A total of 62 sediment samples were collected in a grid pattern that was 400 m x 250 m in the vicinity of the footprint of the barge, as well as three stations from a reference site that was 30 km southwest of the barge footprint. In 1999, there were 70 samples taken in a similar pattern, but the sampling coverage was extended in the area southeast of the barge footprint since that was the previously observed direction of sediment movement. At 12 selected stations in 1998, two 1 kg sediment samples were obtained for laboratory toxicity testing, and 5 kg samples were obtained for identification and enumeration of benthic invertebrate organisms. All sediment samples were analyzed for Aroclor 1242 content using materials and methods previously described (Government of Canada 1997).

Grab samples for PCB analysis, sediment characterization, toxicity testing and benthic invertebrate identification were taken directly from the dredge prior to any homogenization. Samples for PCB analysis were placed in detergent washed glass containers that were subsequently rinsed with distilled water and hexane. The samples were then homogenized in a blender prior to analysis by Phillip Analytical, Halifax, NS.

Sample locations and corresponding PCB concentrations for the May-June 1996, August-October 1996, and May 1997, 1998 and 1999 sampling events were plotted using Surfer® for Windows software, Version 6 (Golden Software Inc. 1998). Where specific latitude and longitude coordinates were not available, those were extrapolated from previously prepared sampling maps showing distances from the *Irving Whale* footprint. Contour lines reflecting five different PCB concentrations: 0.1,1, 10, 100, and 1000 µg/g (as well as 0.01 µg/g for the 1998 map) were generated by Surfer® using grid data files of the PCB concentrations and sample coordinates. Those grid files were created in Surfer® using the kriging interpolation method. For each contour map, the area (in metres squared) represented by each of the PCB concentrations were determined by first converting the sample coordinates to metres, then, using the Surfer® Program, calculating the positive planar area within each contour line.

Snow Crab Sampling and Analysis

In June 1998 and 1999, snow crab samples were collected at twelve locations around the *Irving Whale* site. Those locations were located on the footprint and at 2.5 and 5.0 nautical miles from the site on the four cardinal points of the compass. Two additional sites were located at 1.35 and 2.7 nautical miles southeast of the barge footprint and there was one distant reference site located 30 nautical miles to the north. Sample sites were similar in all years and were identical in 1998 and 1999 except that the reference site in 1998 was 20 nautical miles northwest of the site. Snow crabs were captured using two commercial conical fishing traps at each station. Upon retrieving the traps from the water, approximately 40 male snow crabs having a carapace width ranging from 85 to 135 mm were kept from each station and placed in clean labeled plastic 30 L fish crates. All crabs were kept alive in sample baskets or in the hold of the *Opilio* research ship until dissection in the laboratory.

The crabs were dissected by the Canadian Food Inspection Agency's laboratory, located in Shippegan, New Brunswick (Government of Canada 1997). Briefly, two pooled samples of male snow crabs for both digestive glands and muscle tissues were taken from each site, one sample of digestive gland was analyzed for PCBs and the other samples were archived as a backup sample. All pooled samples of digestive glands were prepared by mixing the entire organ from five individuals. Archived samples of muscle tissues were taken from claws and legs. In addition, samples of digestive glands and meat were extracted from individual crabs taken from the barge footprint site and archived.

The decision to analyze only digestive gland and not meat was based on previous data (Gilbert *et al.* 1998) that showed levels in meat were consistently two orders of magnitude lower than in the digestive glands. If any samples of digestive gland showed PCB levels of concern then further analysis could be conducted on meat or other archived samples.

Laboratory analyses were conducted on the 1999 samples at the DFO Laboratory in Halifax, NS. All tissue samples were homogenized and then saponificated and extracted with hexane. Extracts were purified by size-exclusion chromatography and sulfuric acid treatment. PCB congeners were measured by capillary gas chromatography. The snow crab extracts were analyzed by GC-MSD (5971A) on a MDN-5S capillary column. The MS was operated in the selective ion monitoring (SIM) mode using 4 ions per class for confirmation of chlorobiphenyls. The data were not corrected for recoveries of surrogates. Recoveries of added ^{13}C-77, ^{13}C-153 and ^{13}C-194 (~4 ng/g wet wt.) to digestive glands averaged 88 ± 7, 99± 6, and 99 ± 6, respectively.

The 1998 data were analyzed using HP-5MS capillary column. The new data were produced using an MDN-5S (HP-5MS similar) column and therefore, co-eluting CB combinations may differ. All data tables provide a summation value (ΣCB).

Toxicity Testing

Amphipod Toxicity Test Procedure

Amphiporeia virginiana were field collected at Martinique Beach, NS on July 6, by wet sieving beach sand through a 1 mm sieve. Amphipods remaining in the sieve were netted and

transferred to pre-sieved sand with overlying water for transport and holding in the laboratory within four hours of collection. They were shipped in coolers containing ice to prevent temperature rise during transport. Animals were collected at 15°C and 29 ppt salinity. The animals were acclimated to and maintained at 10 ± 2°C and 28 ± 2 ppt salinity until used for testing on July 10, 1998. The temperature, dissolved oxygen, pH and salinity were monitored daily throughout holding in the laboratory.

On the day prior to starting the test, the two containers of test sediment were combined and homogenized and 175 mL portions were added to each of five 1L glass mason jars. The jars were then filled with 800 mL of clean water of 28 ppt salinity, covered and aerated overnight with oil-free compressed air at a rate of approximately 150 mL/ minute. The control water was a natural seawater from Poine-du-Chene, NB. Tests were conducted according to Environment Canada (1992a).

The following day, amphipods were sieved from their holding sediment. Twenty animals were double counted then added to each of the test vessels. Aeration was ceased for 30 minutes to facilitate burrowing. Testing was performed with a 24 hour light photoperiod with lighting provided by overhead fluorescent fixtures. Testing was performed at 10 ± 1°C. Tests were checked daily for observations, aeration and temperature. Three times a week a replicate of each sample is monitored for temperature, pH, salinity and dissolved oxygen. After 10 days, the contents of each jar were sieved through a 0.5 mm sieve. Any immobile animals were observed under a microscope to determine mortality, which was defined as lack of all movement when observed under a dissecting microscope for 5 - 10 seconds. Any animals missing are assumed to be dead. The mean and standard deviation of each treatment is calculated.

Mean percent survival of amphipods exposed to each test sediment is statistically compared to mean percent survival of amphipods exposed to the clean collection site control sediment. If mean survival in the test sediments is more that 30% lower then mean survival in the collection site control sediment, then the sample is considered toxic. (Environment Canada 1998) Samples are also considered toxic if mean survival in the test sediments is more than 20% lower than mean survival in the reference sediment (Environment Canada 1998).

A reference toxicant test was conducted with cadmium chloride using water only exposures for 96-hours duration in constant dark. Using the mortality data at each test concentration, the 96 hour LC_{50} (concentration calculated to 50% mortality after 96-h exposure) was calculated using the methods of Stephan (1977). The value was entered into the control chart to ensure normal operating conditions were maintained and that the population of amphipods used in the test was of normal sensitivity.

Microtox® Solid Phase Test Procedure

This test was conducted according to Environment Canada (1992b) test method. This method exposes the bacterium to the sediment sample. If toxic materials are present, they interfere with cellular respiration of the organism. This interference is measured as a decrease in light output by the bacterium, *Vibrio fischeri* (previously *Photobacterium phosphoreum*). Testing was performed between July 21 and August 4, 1998.

A aliquot of wet sediment is transferred to a beaker and stirred for 10 minutes with diluent. A dilution series of 12 concentrations and 3 controls are prepared from this mixture. Bacterial reagent is added to the dilutions and incubated at 15°C for 20 minutes. These dilutions are filtered and the filtrate is transferred to the Microtox® analyzer. After 10 minutes in the analyzer bioluminescence is recorded. Statistics are performed on the data to calculate EC_{50} on a wet weight basis (the concentrations at which light output by a population of the luminescent bacterium is reduced by 50% when compared to the untreated control population). Three aliquots of the sediment are dried at 100°C for 24 hours and the percentage moisture determined. The EC_{50} is corrected for moisture content and quoted on a dry weight basis as ppm. A reference toxicant using zinc sulfate was analyzed using the Microtox® basic assay prior to the analysis of the sediments. This test was conducted according to Environment Canada (1992b) test method. The EC_{50} for this analysis was entered into the Shewhart control charts to ensure the test was within standard operating limits, and that the population of bacteria used in the test was of normal sensitivity.

Benthic Invertebrate Analysis

The benthic invertebrate identification and enumeration were conducted by Envirosphere Consultants Ltd., Windsor, NS. Organisms were identified to an appropriate taxonomic level using conventional literature for the groups involved. Species abundance, number of species, Shannon-Wiener diversity and Pielou's evenness (Pielou 1974) were calculated from the data. In addition, cumulative percent frequency (Clarke and Warwick 1994), geometric dominance curves (Gray and Pearson 1982; Clarke and Warwick 1994) and proportional composition by taxon (Pocklington and Wells 1992; Clarke and Warwick 1994) were derived in order to further evaluate whether PCB contamination was having any effect on benthic community structure.

All statistical analyses on PCB sediment concentrations were conducted using Statgraphics® Plus for Windows Software, Version 3 (Manugistics Inc., 1997). Pearson correlations and Spearman rank correlations were run for two 1998 data sets:

1. PCB, total organic carbon (TOC) and particle size data for all samples; and

2. PCB, TOC, particle size, toxicity (Microtox® solid-phase EC_{50} and *Amphiporeia virginiana* survival tests), and benthic biota analyses for 12 samples.

While every combination of variables was analyzed, only those showing statistically significant correlations at the 95% confidence level were reported.

RESULTS AND DISCUSSION

PCBs in Sediment

The results of PCB analysis and the physical characterization of sediment samples taken in 1998 from the vicinity of the *Irving Whale* footprint are presented in Table 1, and the contour plot of those concentrations is presented in Figure 1. It should be noted that the depth of sediments in that area seldom exceeds 15 cm (Government of Canada 1997). A calculation of

the total area in various concentration ranges indicated an area of 664 m^2 contaminated to concentrations exceeding 1000 µg/g. That area progressively increased up to a total of 80,792 m^2 that was contaminated in excess of 0.01 µg/g. In contrast to previous sampling, it was not possible to calculate the total amounts of PCBs within sediments included in those contour ranges, since no measurements of sediment depth were obtained during the 1998 sampling.

The results of the PCB analysis of sediment samples taken in 1999 are presented in Table 2, and the contour plot of those concentrations is presented in Figure 2. Overall, the concentrations again were substantially reduced compared with 1998 data. There were no samples that were greater than 1000 µg/g, and only three of the 70 samples exceeded 100 µg/g. The calculations of the total area in various concentration ranges revealed a overall three-fold reduction in the area contaminated at concentrations between 100 and 1000 µg/g. There was again an approximate doubling of the area contaminated below 100 µg/g compared with 1998 values. The increasing area of low contamination (0.01 - 0.10 µg/g) is within the range of previously developed threshold effect levels (0.02 µg/g, Canadian Council of Ministers of the Environment (CCME) 1999); site specific criteria (0.02 - 0.125 µg/g, Cantox 1996) and Interim Ocean Disposal Criterion (0.10 µg/g, CEPA 1991). Similar plots were done for all previous sampling efforts (Figures 3, 4, 5).

This dispersion pattern, presented graphically in Figure 6, is similar to that noted by Gilbert *et al.* (1998), which is primarily a spreading effect attributed to physical dispersion. PCBs bound with or entrained in sediments dispersed primarily to the southeast of the barge footprint. This apparent increase in area of lower contamination may be an artifact caused by changes in sample coverage between years. Results strongly suggest that dispersion is the primary mechanism for apparent PCB changes in sediment, rather than physical/chemical/biological degradation.

PCBs in Snow Crab

No snow crab samples collected in June 1998 had PCB concentrations that exceeded the Canadian consumption limit of 2 µg/g in their digestive glands (Table 3). Total PCB concentrations in the digestive glands ranged from 0.084 to 0.690 µg/g, with the highest levels unexpectedly being found at the remote site and the next highest level of 0.580 µg/g being

found at the barge footprint. In 1999, no samples exceeded the Canadian consumption limit and ranged from 0.085 to 0.580 µg/g with the highest level being on the footprint (Figure 7). By comparison, 20% of the pooled snow crab samples of digestive glands collected in October 1996 reached or exceeded the 2 µg/g limit . PCB concentrations for 1997 digestive gland samples are reduced from 1996 concentrations and none exceeded the Canadian consumption guideline.

PCB concentrations in snow crab tissue were also below concentrations previously observed for the St. Lawrence Estuary (Gilbert and Walsh 1996). Current PCB levels in the muscle tissue (Gilbert *et al.* 1998) and digestive gland of snow crabs collected around the *Irving Whale* site are well below Canadian guidelines for human consumption. In addition, further elimination of less persistent low chlorinated PCBs from snow crab tissues could occur during their dispersion away from the barge footprint area, depending on the individual's rate of movement. While the possibility of catching a few unmarketable crabs around the *Irving Whale* site cannot be dismissed, given the high PCB concentrations in sediment still found near the barge footprint, at present, the probability of catching and marketing snow crabs that are contaminated above the 2 µg/g limit outside the current fishing exclusion zone are considered to be low.

Toxicity Testing (1998)

The results of toxicity testing are presented in Table 4. The mean survival of amphipods from the control site was 99%. The only samples from the *Irving Whale* recovery site that were toxic to *A. virginiana* were Station H4, which had a 0% survival rate and a PCB concentration of 250 µg/g, and Station K4, which had a 45% survival rate and a PCB concentration of 28 µg/g. Those toxic responses were strongly correlated with PCB concentration in sediment (Pearson correlation $R = -0.92$, $p < 0.001$)(Table 5) All other samples from the site were non-toxic to *A. virginiana* indicating that the toxic threshold of PCBs in the *Irving Whale* sediment for that organism is somewhere between 1.5 µg/g and 28 µg/g. Amphipod survival was not significantly correlated with percent sand or percent fines content of samples (Pearson correlation $p > 0.05$).

The toxic response by *V. fischeri* to the sediment samples was a more graded response. The 20 min EC_{50}s ranged from 1,480 to 154,000 ppm (dry weight corrected).

The reference sample that is the closest match in grain size to the test samples is Station Ref 1. That sample had an 20 min EC_{50} of 36,400 ppm (Table 4, Figure 8). All the samples, except Stations D4 and Ref 3, had EC_{50}s significantly lower than this reference sample (ANOVA $p < 0.05$). Comparison with the reference sample Station Ref 1, would lead to the conclusion that all stations except Station D4 and Station Ref 3 had some degree of toxicity to the bacteria. Therefore, all samples except Reference Sites 1 and 3, and station 57 D4, show low to moderate toxicity to the bacteria in the Microtox® test. However, Microtox® EC_{50} was not significantly correlated with PCB concentration.

Microtox® can be affected by grain size (Tay *et al.* 1998). Clean samples of similar grain size, about 92% sand and 8% fines, have been tested in the laboratory and resulted in 20 min EC_{50}s about 28,000 ppm. In this study, Microtox® response was not significantly correlated to the percent sand and percent fines content of the samples ($p > 0.05$).

The interim guideline for the Environment Canada Ocean Disposal Program is that a sample is toxic in the Microtox® solid phase test if the EC_{50} is less than 1,000 ppm corrected for dry weight of solids (Environment Canada 1996) in the absence of a suitable reference sediment with which to compare the test sample. Therefore, none of these sediment samples would be considered toxic under the Environment Canada Ocean Disposal Program, Microtox solid phase test criteria.

Benthic Invertebrates (1998)

The cumulative percent frequency curves, in which species are ranked from the least to the most abundant in each sample is plotted versus number of species, is presented in Figure 9. All curves had relatively gradual rises, which is typical of undisturbed communities (Clarke and Warwick 1994) . Although curves for the samples from the *Irving Whale* site had a sharper initial rise than the control site, the difference cannot be linked to PCB content, and may be related to differences in sediment type between sites. Benthic invertebrate samples from Caraquet, NB, and Cheticamp, NS, which are relatively less contaminated (reference sites) from the same general location, showed similar gradual curves.

The geometric dominance curves; which estimate the number of species in each community that occur in abundance classes separated by a factor of 2, are presented in Figure 10. Those curves also showed trends indicative of undisturbed communities, typically revealing a high proportion of the species occurring in small numbers. Similar patterns were demonstrated in plots for samples from the control sites.

Since certain organisms, such as polychaetes, are frequently considered to be indicators of environmental contamination, because their small size and fast reproductive rates allow them a colonizing advantage (Pocklington and Wells 1992; Clarke and Warwick 1994), plots were made of polychaetes as percent of the total number of species. The contribution of polychaete worms to the biological community, in terms of percent of total species, at sites in the vicinity of the *Irving Whale* footprint appears to be similar, although polychaetes make up higher proportions there than at some of the reference sites (Figure 11). The pattern of polychaete contribution at the *Irving Whale* sites, in which polychaetes appear to be slightly less important further from the footprint, may be indicative of some site stress, however it is not marked and could be related to sediment characteristics. Furthermore, the fact that polychaetes made up a greater percentage of the benthic community in the samples that were considered to be upgradient of the predominant current may question the reliability of this indicator.

An attempt was also made to determine the level of similarity between biological communities using clustering of samples according to the Czekanowski Index of Similarity. The resulting cluster diagram (Figure 12) indicates that there was a greater similarity among the reference samples than the samples from the site of the *Irving Whale*. It cannot be concluded, however, that said clustering was due to PCB content of the sediments and in fact was probably related to the physical characteristics of the sediments, specifically grain size (Figure 13). Figure 12 however, shows that the benthic community in samples H4 and K4, which are the only two samples toxic to the amphipods in the toxicity tests and contain the highest concentrations of PCBs, formed a separate cluster indicating that the communities are distinct from those in other samples at the *Irving Whale* site.

To determine whether factors such as PCB concentration, total organic carbon, and percent of fine particles could be affecting Shannon Wiener diversity, Pielou's Evenness, number of individuals per sample and number of species per sample, Pearson Correlations were

calculated between the factors. Table 5 presents the results of those calculations where correlations were judged to be significant. As can be seen from those results, although PCB concentration is correlated with Pielou's Evenness and number of individuals per sample, other factors such as total organic carbon and percent fines are also strongly correlated. That probably means that PCB contamination is associated with certain sediment characteristics and it is not possible to distinguish what individual characteristics, if any, are causing slight community changes.

Generally, in terms of the selected measures of community structure (cumulative percentage dominance and distribution in geometric size classes), the communities in the vicinity of the *Irving Whale* site were similar to the reference site and two sample sites from the Gulf of St. Lawrence. Polychaete dominance did appear, however, to indicate a difference from the other sites (higher dominance of polychaetes at the *Irving Whale* site), but that could be attributed to sediment type (sandy versus gravely at the control, mixed sandy to rocky at Caraquet, and gravely to rocky at Cheticamp). Unfortunately, no communities from similar substrate type and depth to that at the *Irving Whale* site were available for comparison to the sites at the *Irving Whale* footprint.

Based on evidence collected, it appears that the benthic community structure in the vicinity of the *Irving Whale* footprint has not been substantially disturbed. As an added note, Clarke and Warwick (1994) observed that communities having slight disturbance may have higher diversity than less disturbed communities. However, without more detailed sampling and analysis of the seabed in the vicinity of the footprint, it is not possible to assess whether that interpretation applies here.

CONCLUSIONS

The following summary and conclusions can be drawn from the 1998 and 1999 sampling program:

1. The areas of high PCB contamination (in excess of 1000 µg/g) continue to decrease in size each year. However, this continued dispersion and spreading of the PCB contaminated sediments will increase the area of lower contamination (< 1 µg/g).

2. In 1998, there was a strong correlation between amphipod survival and PCB concentration of sediment samples and only those sediments that had PCB concentrations in excess of 1.5 μg/g had any toxic effect on the benthic amphipod *Amphiporeia virginiana*. In contrast, in the Microtox® test, almost all of the samples from the vicinity of the footprint indicated some toxic response when compared to the reference station but there was no correlation between PCB concentration of sediment and Microtox® response. Based on Environment Canada Ocean Disposal Microtox® solid phase test criteria, the samples were deemed non-toxic.

3. In 1998, the benthic community in the vicinity of the footprint appeared to be slightly different than those of reference sites. However, the findings do not indicate a substantial impact. The reasons for any differences observed could not be determined, and are likely related to physical characteristics of the sediment. The benthic communities in samples H4 and K4, which are the only two samples toxic to the amphipods in the toxicity tests and contain the highest concentrations of PCBs, are distinct from other samples at the *Irving Whale* site when using the Czekanowski Index of Similarity.

4. The PCB concentrations in digestive glands of snow crab continue to decline and were well below the Canadian Guideline for food consumption. As a precautionary measure, however, it is recommended that the current fishing exclusion zone around the Irving Whale site be maintained. As long as this closure is in place, the risk for the Gulf snow crab fisheries to be affected by the local PCB contamination around the *Irving Whale* site is negligible. In addition, the risk of PCB transfers to biota by disturbing contaminated sediments around the barge footprint with fishing gear is also eliminated. The same logic was previously applied and accepted to justify maintenance of that zone (Gilbert, *et al.*, 1998).

5. The continued reduction in sediment PCB concentrations, the continued reduction in PCB concentrations in snow crab tissues and absence of residues that exceed Canadian consumption guidelines, lack of marked toxicity of sediments, and lack of substantial

disturbance of benthic community structure, support the decision reached in the spring of 1999 not to remove the contaminated sediments at the site.

FURTHER RESEARCH

Plans are currently in preparation for additional sampling of snow crabs around the site of the *Irving Whale* in 2000. If further results continue to show levels of PCBs below the levels of concern after the 2000 survey, considerations should be given to a decreasing frequency of the crab sampling and possibly reducing the size of the fishing exclusion zone.

Additional research as to the fate of missing PCBs is being conducted as opportunities arise on related projects (M. Gilbert, pers. com.). Those results will be reported separately.

Based on the lack of substantial risk presently posed by sediment contamination at the site and the fact that the pattern of dispersion of PCBs in sediments is now reasonably well established, there is probably little need for additional sediment sampling at the site.

REFERENCES

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian Environmental Quality Guidelines. Winnipeg. ISBN 1-896997-34-1. Publication No. 1299.

Cantox. 1996. Ecological risk assessments and development of site-specific PCB sediment remediation criteria for the protection of snow crab and related species at the *Irving Whale* site. Report for Environment Canada, 31 p.

CEPA. 1991. Interim contaminant testing guidelines for ocean disposal, Atlantic Region. Canadian Environmental Protection Act, Part VI, Ocean Disposal. 6 p.

Clarke, K.R. and R.M. Warwick. 1994. Change in marine communities. An approach to statistical analysis and interpretation. Natural Environment Research Council, UK, 144 p.

Environment Canada. 1992a. Biological test method: Acute tests for sediment toxicity using marine or estuarine amphipods. Report EPS 1/RM/26. Environment Canada, Environmental Protection. Ottawa.

Environment Canada. 1992b. Biological test method: Toxicity test using luminescent bacteria (*Photobacterium phosphoreum*). Report EPS 1/RM/24. Environment Canada, Environmental Protection, Ottawa, K1A 0H3.

Environment Canada. 1996. 1996 national monitoring at ocean disposal sites. Environment Canada, Ottawa, Ontario. 1996.

Environment Canada. 1998. Reference Method for Determining Acute Lethality of Sediment to Marine or Estuarine Amphipods. Environment Canada, Ottawa, Ontario. December 1998. Report EPS 1/RM/35.

Gilbert, M and G. Walsh (eds). 1996. Potential consequences of a PCB spill from the barge *Irving Whale* on the marine environment of the Gulf of St. Lawrence. Can Tech. Rep. Fish. Aquat. Sci. 2113: xiii + 59 pp.

Gilbert, M., R. Alexander, J. Arsenault, W. Ernst, W. Fairchild, P. Hennigar, G. Julien, T. King, M. Lebeuf, and D. LeFaivre. 1998. PCB contamination of sediments and snow crab (*Chionoecetes opilio*) around the site of the *Irving Whale* barge after its recovery: A Final Report. Can. Tech. Report. Fish. Aquatic Sciences 2204.

Gilbert, M. 1999. Maurice Lamontagme Institute. Mont-Joli, Quebec. Personal communication.

Golden Software Inc., Golden Colorado. 1998. Surfer® software for Windows. Version 6.

Government of Canada. 1997. Scientific assessment of the PCB contamination in sediments and biota around the site of the sinking of the barge *Irving Whale*. Status Report, Fisheries and Oceans Canada and Environment Canada. xii + 48 p.

Gray, J.S. and T.H Pearson. 1982. Objective selection of sensitive species indicative of pollution-induced change in benthic communities. I. Comparative methodology. Mar. Ecol. Prog. Ser. 66: 285-299.

Jacques Whitford Environmental Ltd. 1998. *Irving Whale* sediment remediation options evaluation. Report prepared for Environment Canada, prepared by Jacques Whitford Environmental Limited with assistance from CANTOX Environmental in Association with the *Irving Whale* Site Remediation Steering Group, VII + 56 pp + appendices.

Manugistics Inc., 1997. Statgraphics® Plus for Windows software for Windows, Version 3. Rockville, Maryland.

Pielou. 1974. Ecological Diversity. John Wiley and Sons. New York.

Pocklington, P. and P.G. Wells. 1992. Polychaetes, key taxa for marine environmental quality monitoring. Mar. Poll. Bull., 24: 593-598.

Stephan, C.E. 1977. Methods for calculating an LC_{50} p 65-84 **In**: Mayer, F.L. and J.L. Hamelink (eds.) Aquatic toxicity and hazard evaluation. American society for testing and materials. Philadelphia, Pa. ASTM STP 634.

Tay, K.L., K.G. Doe, A.J Macdonald and K. Lee. 1998. The influence of particle size, ammonia and sulfide on toxicity of dredged materials for ocean disposal. Pp 559-574, **In**: Microscale testing in aquatic toxicology: Advances, techniques, practice. Wells, P.G., K. Lee and C. Blaise. CRC Press 679 pp.

Table 1 - PCB content and physical characteristics of 1998 sediment samples from the vicinity of the *Irving Whale* footprint.

Site #	Site	Easting (UTM)	Northing (UTM)	Latitude (DD)	Longitude (DD)	PCB* (µg/g)	PCB1 (µg/g)	PCB2 (µg/g)	PCB3 (µg/g)	TOC (g/kg)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (% silt+clay)
1	-a-9	475283.0	5245952.4	47.3666	63.3274	0.14				2.1	0.2	91.1	2.4	6.3	8.7
2	b-9	475308.5	5245985.3	47.3669	63.3270	0.16				1.5	0.1	91.8	2.5	5.7	8.2
3	d-9	475330.5	5246007.0	47.3671	63.3267	0.39				1.6	0.1	92.0	2.1	6.0	8.1
4	h-9	475359.0	5246033.5	47.3673	63.3264	0.23									
5	k-9	475387.6	5246072.8	47.3677	63.3260	0.16	0.16	0.16	0.17	1.5	0.1	88.9	3.0	8.1	11.1
6	m-9	475410.0	5246091.4	47.3678	63.3257	0.25				1.7	0.1	91.9	2.1	6.0	8.1
7	o-9	475440.1	5246128.1	47.3682	63.3253	0.25				1.3	1.3	91.7	1.9	5.1	7.0
8	o-6	475392.3	5246165.4	47.3685	63.3259	0.26				2.0	0.1	87.2	3.8	9.0	12.8
9	m-6	475365.8	5246143.4	47.3683	63.3263	0.31				1.7	0.1	91.5	2.3	6.2	8.5
10	k-6	475342.7	5246109.5	47.3680	63.3266	1.27	1.20	1.30	1.30	1.6	0.1	91.9	2.1	6.0	8.1
11	h-6	475313.0	5246074.4	47.3677	63.3270	0.87				1.6	0.1	91.3	2.3	6.4	8.7
12	d-6	475287.2	5246053.0	47.3675	63.3273	0.41				1.4	0.1	93.8	1.4	4.8	6.2
13	b-6	475268.3	5246041.7	47.3674	63.3276	0.24				1.6	0.1	93.7	1.6	4.7	6.3
14	-a-6	475236.8	5245997.3	47.3670	63.3280	0.16				1.6	0.1	92.2	2.3	5.5	7.8
15	-a-4	475205.1	5246011.9	47.3671	63.3284	0.21				1.3	0.1	91.4	2.5	6.1	8.6
16	b-4	475236.5	5246052.1	47.3675	63.3280	0.34				1.9	0.1	92.3	1.9	5.8	7.7
17	d-4	475251.8	5246077.7	47.3677	63.3278	1.10				1.8	0.1	91.9	2.2	5.9	8.1
18	h-4	475278.4	5246110.2	47.3680	63.3274	11.00				1.6	0.1	91.6	2.3	6.1	8.4
19	k-4	475311.0	5246132.9	47.3682	63.3270	1.43	1.50	1.40	1.40	1.8	0.1	90.3	2.6	7.1	9.7
20	m-4	475333.3	5246160.0	47.3684	63.3267	0.70				1.7	0.1	92.1	2.0	6.0	8.0
21	o-4	475366.6	5246198.9	47.3688	63.3263	0.40				2.4	0.3	91.2	2.5	7.1	9.6
22	o-2	475325.2	5246223.5	47.3690	63.3268										
23	m-2	475302.1	5246188.2	47.3687	63.3271	0.75				1.6	0.1	92.3	1.8	5.8	7.6
24	k-2	475271.9	5246165.0	47.3685	63.3275	2.20	2.20	1.90	2.50	1.7	0.1	90.6	2.6	6.8	9.4
25	h-2	475248.8	5246128.1	47.3681	63.3278	3.00				0.9	0.1	94.1	1.4	4.5	5.9
26	d-2	475218.0	5246102.7	47.3679	63.3282	2.00									
27	b-2	475203.6	5246074.8	47.3677	63.3284	0.33				1.6	0.1	92.3	1.9	5.8	7.7
28	-a-2	475172.5	5246045.0	47.3674	63.3288	0.18				1.3	0.1	92.4	2.1	5.5	7.6
29	e15	475008.6	5246287.8	47.3696	63.3310	1.20				1.4	0.1	91.7	2.3	6.0	8.3
30	h15	475029.5	5246311.6	47.3698	63.3307	0.49				1.5	0.1	91.9	2.3	5.8	8.1
31	k15	475059.7	5246345.8	47.3701	63.3303	1.53	1.60	1.50	1.50	1.5	0.1	93.2	1.7	5.1	6.8
32	b13	475015.8	5246233.4	47.3691	63.3309	0.51				1.8	0.1	91.2	2.5	6.3	8.8
33	d13	475045.4	5246261.3	47.3693	63.3305	1.60				2.0	0.1	89.1	3.1	7.9	11.0

* Where duplicates and triplicates were analyzed, value in this column is average of these results.

Table 1 (Continued) - PCB content and physical characteristics of 1998 sediment samples from the vicinity of the *Irving Whale* footprint.

Site #	Site	Easting UTM	Northing UTM	Latitude DD	Longitude DD	PCB* (µg/g)	PCB1 (µg/g)	PCB2 (µg/g)	PCB3 (µg/g)	TOC (g/kg)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (% silt+clay)
34	h13	475062.0	5246288.0	47.3696	63.3303										
35	k13	475090.9	5246312.5	47.3698	63.3299	27.00				3.8	0.3	81.7	5.5	12.5	18.0
36	m13	475112.8	5246343.7	47.3701	63.3296	14.00				2.5	0.2	88.5	3.2	8.1	11.3
37	n12	475142.8	5246343.3	47.3701	63.3292	11.00									
38	q12	475171.5	5246376.3	47.3704	63.3289	1.10				1.7	0.1	92.9	1.8	5.4	7.2
39	b11	475041.8	5246215.7	47.3689	63.3306	1.30				2.5	1.1	86.7	3.4	8.7	12.1
40	e11	475074.0	5246231.8	47.3691	63.3301	4.70				1.4	0.1	91.0	2.2	6.7	8.9
41	h11	475091.1	5246257.6	47.3693	63.3299	7.90				3.5	6.1	80.5	3.3	10.1	13.4
42	k11	475123.1	5246287.1	47.3696	63.3295	140.00	130.00	160.00	130.00	1.9	0.4	90.7	2.3	6.6	8.9
43	n10	475168.9	5246330.0	47.3700	63.3289	6.40				2.2	0.1	90.6	2.4	7.0	9.4
44	-a0	475139.3	5246077.8	47.3677	63.3293	0.33				2.6	1.8	86.3	3.3	8.6	11.9
45	b0	475173.0	5246102.1	47.3679	63.3288	0.27				1.9	0.1	90.5	2.5	7.0	9.5
46	d0	475186.0	5246121.8	47.3681	63.3287	0.68				2.2	1.6	88.8	2.6	7.1	9.7
47	h0	475218.2	5246156.1	47.3684	63.3282	22.00				1.0	0.1	95.7	0.9	3.4	4.3
48	k0	475239.7	5246184.2	47.3686	63.3279	6.83	6.40	7.00	7.10	2.8	0.3	87.4	3.6	8.7	12.3
49	m0	475271.3	5246218.7	47.3690	63.3275	3.70				2.7	0.1	88.1	6.5	5.4	11.9
50	o0	475294.4	5246240.4	47.3692	63.3272	1.50									
51	m2	475241.6	5246241.4	47.3692	63.3279	3.70				3.8					
52	k2	475208.8	5246208.6	47.3689	63.3284	52.3	32.00	33.0	92.0	2.5	0.4	84.8	4.0	10.8	14.8
53	h2	475186.3	5246185.5	47.3687	63.3287	120.00				3.8	2.6	83.3	5.0	9.1	14.1
54	d2	475158.5	5246153.5	47.3684	63.3290	0.93				3.0	1.4	86.9	3.4	8.3	11.7
55	b2	475143.5	5246131.6	47.3682	63.3292	0.52				2.4	0.1	87.8	3.5	8.7	12.2
56	b4	475099.3	5246157.4	47.3684	63.3298	0.27				1.1	0.1	92.2	2.1	5.7	7.8
57	d4	475123.2	5246179.0	47.3686	63.3295	0.56				1.7	0.1	94.7	1.3	4.0	5.3
58	h4	475158.3	5246220.1	47.3690	63.3290	250.00				2.0	0.1	91.2	2.2	6.6	8.8
59	k4	475178.6	5246234.0	47.3691	63.3288	28.3	31.00	23.0	31.0	2.9	1.1	83.7	4.1	11.1	15.2
60	d5	475117.5	5246186.8	47.3687	63.3296	3.70				3.0	6.5	80.1	3.7	9.6	13.3
61	m6	475186.0	5246284.9	47.3696	63.3287	110.00				3.2	7.9	78.7	3.8	9.5	13.3
62	d7	475093.2	5246216.1	47.3689	63.3299	5.30				1.6	0.1	92.4	3.5	4.2	7.7
63	k7	475154.0	5246259.8	47.3693	63.3291	1827	3200.00	980	1300	3.0	0.9	85.3	3.7	10.2	13.9
64	h8	475127.6	5246254.2	47.3693	63.3294	12.00									
65	Ref	582021.2	5164953.5	46.6331	61.9284	<0.01				0.7	2.6	93.0	2.7	1.7	4.4
66	Ref	582038.1	5164968.9	46.6333	61.9282	<0.01				0.9	75.4	22.6	1.1	1.0	2.1
67	Ref	582049.6	5164989.7	46.6334	61.9281	<0.01				1.6	18.5	77.9	2.1	1.6	3.7

* Where duplicates and triplicates were analyzed, value in this column is average of three results.

Table 2 - PCB content of 1999 sediment samples from the vicinity of the *Irving Whale* footprint.

Sample ID	Latitude	Longitude	PCB (µg/g)	Sample ID	Latitude	Longitude	PCB (µg/g)
1-T-13	47 22.099	63 19.428	0.15	31-K+15	47 22.209	63 19.816	0.57
2-O-13	47 22.064	63 19.471	0.12	32-H+15	47 22.189	63 19.842	1.20
3-K-13	47 22.028	63 19.516	0.26	33-E+15	47 22.174	63 19.865	0.39
4-D-13	47 21.996	63.19.555	0.22	34-M+13	47 22.202	63 19.775	6.30
5-A-13	47 21.968	63 19.566	1.00	35-K+13	47 22.188	63 19.792	7.00
6-E-13	47 21.936	63 19.641	nd	36-H+13	47 22.175	63 19.818	0.83
7-T-9	47 22.127	63 19.469	0.12	37-E+13	47 22.166	63 19.832	0.89
8-O-9	47 22.090	63 19.517	0.30	38-B+13	47 22.147	63 19.851	0.64
9-M-9	47 22.075	63 19.541	0.77	39-Q+12	47 22.224	63 19.728	2.40
10-K-9	47 22.061	63 19.558	0.37	40-N+12	47 22.207	63 19.748	1.20
11-H-9	47 22.044	63 19.586	0.74	41-N+10	47 22.200	63 19.732	1.40
12-D-9	47 22.026	63 19.602	0.79	42-K+11	47 22.177	63 19.769	19.00
13-B-9	47 22.014	63 19.614	0.34	43-H+11	47 22.159	63 19.793	16.00
14-A-9	47 21.995	63 19.641	0.15	44-E+11	47 22.146	63 19.806	1.40
15-T-6	47 22.146	63 19.508	0.28	45-B+11	47 22.133	63 19.828	0.40
15-T-6 (dup)	**47 22.146**	**63 19.508**	**0.21**	**45-B+11 (dup)**	**47 22.133**	**63 19.828**	**0.47**
16-O-6	47 22.111	63 19.551	0.40	46-K+7	47 22.164	63 19.747	180.00
17-M-6	47 22.096	63 19.578	0.82	47-H+8	47 22.150	63 19.778	80.00
18-K-6	47 22.083	63 19.595	0.47	48-D+7	47 22.135	63 19.794	130.00
19-H-6	47 22.061	63 19.619	1.30	49-M+6	47 22.175	63 19.722	29.00
20-D-6	47 22.050	63 19.638	0.49	50-D+5	47 22.122	63 19.776	6.10
21-B-6	47 22.038	63 19.656	0.34	51-K+4	47 22.142	63 19.721	47.00
22-A-6	47 22.019	63 19.679	0.14	52-H+4	47 22.130	63 19.734	110.00
23-O-4	47 22.127	63 19.577	0.34	53-D+4	47 22.121	63 19.750	2.40
24-M-4	47 22.110	63 19.603	0.43	54-B+4	47 22.101	63 19.780	0.79
25-K-4	47 22.091	63 19.620	0.57	55-T+2	47 22.205	63 19.608	1.10
26-H-4	47 22.081	63 19.642	0.78	56-M+2	47 22.152	63 19.669	No sample
27-D-4	47 22.066	63 19.664	0.89	57-K+2	47 22.132	63 19.693	24.00
28-B-4	47 22.051	63 19.675	0.22	58-H+2	47 22.122	63 19.714	63.00
29-A-4	47 22.033	63 19.702	0.18	59-D+2	47 22.105	63 19.735	1.50
30-Q+15	47 22.240	63 19.769	1.30	60-B+2	47 22.090	63 19.750	0.45
30-Q+15 (dup)	**47 22.240**	**63 19.769**	**1.20**	**60-B+2 (dup)**	**47 22.090**	**63 19.750**	**0.43**

Table 2 (continued) - PCB content of 1999 sediment samples from the vicinity of the *Irving Whale* footprint.

Sample ID	Latitude	Longitude	PCB (µg/g)	Sample ID	Latitude	Longitude	PCB (µg/g)
61-O+0	47 22.147	63 19.628	0.78	69-O-2	47 22.139	63 19.605	1.10
62-M+0	47 22.139	63 19.647	1.20	70-M-2	47 22.119	63 19.624	0.87
63-K+0	47 22.120	63 19.673	3.20	71-K-2	47 22.107	63 19.647	1.40
64-H+0	47 22.106	63 19.688	61.00	72-H-2	47 22.092	63 19.667	1.80
65-D+0	47 22.085	63 19.716	1.70	73-D-2	47 22.073	63 19.692	0.69
66-B+0	47 22.074	63 19.727	0.24	74-B-2	47 22.063	63 19.701	0.38
67-A+0	47 22.061	63 19.751	0.15	75-A-2	47 22.045	63 19.728	0.24
68-T-2	47 22.174	63 19.562	0.44	75-A-2 (dup)	47 22.045	63 19.728	0.18

Table 3 - Concentration of total PCBs (78 congeners, µg/g wet wt.) in the digestive glands of pooled snow crab samples collected around the *Irving Whale* site in October 1996, May 1997, June 1998 and June 1999.

Sample location	Digestive gland	Digestive gland	Digestive gland	Digestive gland
	October 1996	May 1997	June 1998	June 1999
Barge footprint				
0-N-1	2.50	0.900	0.310/0.290[2]	0.580
0-N-2	27.20	0.630 / 0.650 [2]	0.560	
0-N-1[I]	0.68	0.410		
0-N-2[I]	0.32	0.450		
0-N-3[I]	1.10	0.420		
0-N-4[I]	0.54	0.250		
0-N-5[I]	0.72	0.330		
North				
0.54-N-1	0.31	–		
1-N-1	2.10	–		
2.5-N-1	–	0.410	0.300	0.280
5-N-1	–	0.450	0.430/0.370[2]	0.380
30-N-1	0.20	0.250 / 0.250 [2]		0.085
Northwest				
20-NW-1			0.690	
East				
0.54-E-1	2.00	–		
1-E-1	0.47	–		
2.5-E-1	0.16	0.520	0.320	0.350
5-E-1	–	0.310	0.270	0.140
Southeast				
0.13-SE-1	0.76	–	0.330/0.320[2]	0.270
0.27-SE-1	0.55	–	0.330/0.320[2]	0.240
0.54-SE-1	0.96	–		
1-SE-1	0.46	–		
1.35-SE-1	0.27	0.460		
2.7-SE-1	0.55	0.340		
5.4-SE-1	0.96	–		
South				
0.54-S-1	0.29	–		
1-S-1	3.30	–		
2.5-S-1	0.25	0.320	0.180	0.380/0.350[2]
5-S-1	–	0.230	0.086/0.084[2]	0.140
West				
0.54-W-1	0.25	–		
1-W-1	0.43	–		
2.5-W-1	–	0.320	0.270	0.230
5-W-1	–	0.480	0.250/0.270[2]	0.280

[1] Samples are coded as follows: distance from the barge footprint (nautical miles) – Orientation from the barge footprint – Laboratory number

[2] Replicate samples.

[I] Represents individuals and not pools

Table 4 - Results of toxicity testing in 1998 using *Amphiporeia virginiana* and *Vibrio fischeri* of selected sediment samples from the vicinity of the *Irving Whale* footprint.

Sample Identification	*A. virginiana* 10-day Sediment Test (Percent Survival)	Solid Phase Microtox® Test EC_{50} as mg/L	PCB Concentration (µg/g)
Control	99 ± 2.2	--	--
Station 3, D9	99 ± 2.2	10,200	0.39
Station 5, K9	97 ± 4.5	4,620	0.16
Station 6, M9	95 ± 6.1	5,150	0.25
Station 29, E15	94 ± 6.5	7,780	1.2
Station 30, H15	95 ± 5.0	8,570	0.49
Station 31, K15	97 ± 4.5	11,400	1.53
Station 57, D4	99 ± 2.2	46,100	0.56
Station 58, H4	0 ± 0	2,040	250
H4 Duplicate	--	1,480	--
Station 59, K4	45 ± 19.4	2,770	28
Station 65, Ref 1	100 ± 0	36,400	>0.01
Station 66, Ref 2	98 ± 2.7	15,200	>0.01
Station 67, Ref 3	98 ± 2.7	118,000	>0.01
Ref 3, Duplicate	--	154,000	--

Table 5 - Correlation between various biological parameters and sediment characteristics of 1998 samples from the vicinity of the *Irving Whale* that were judged to be significant.

Biological Parameter	Sediment Characteristic	Pearson Correlation	
		r	p
Shannon-Weiner Diversity	Total Organic Carbon	-0.76	0.004
Pielou's Evenness	PCB Concentration	0.68	0.016
	Total Organic Carbon	-0.84	0.001
	Percent Fines	-0.61	0.037
# Individuals Per Sample	PCB Concentration	0.74	0.004
	Total Organic Carbon	0.80	0.002
	Percent Fines	0.74	0.006
# Species Per Sample	Percent Gravel	0.79	0.002
Amphipod survival	PCB concentration	-0.92	<0.001

n = 12 for all calculations
R = correlation coefficient
P = probability

Figure 1. PCB concentrations in sediments at the *Irving Whale* site, 1998.

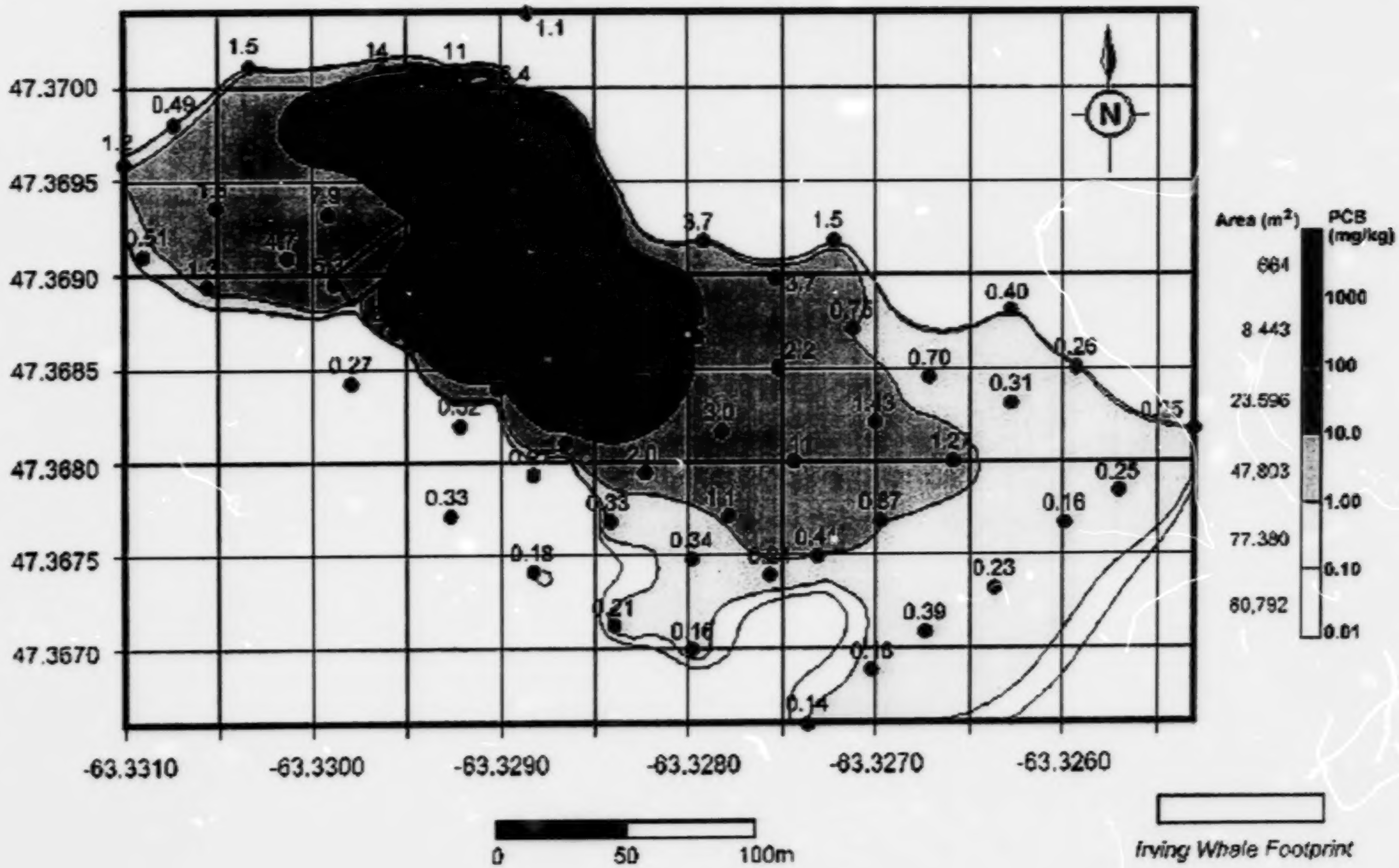


Figure 2. PCB concentrations in sediments at the *Irving Whale* site, 1999.

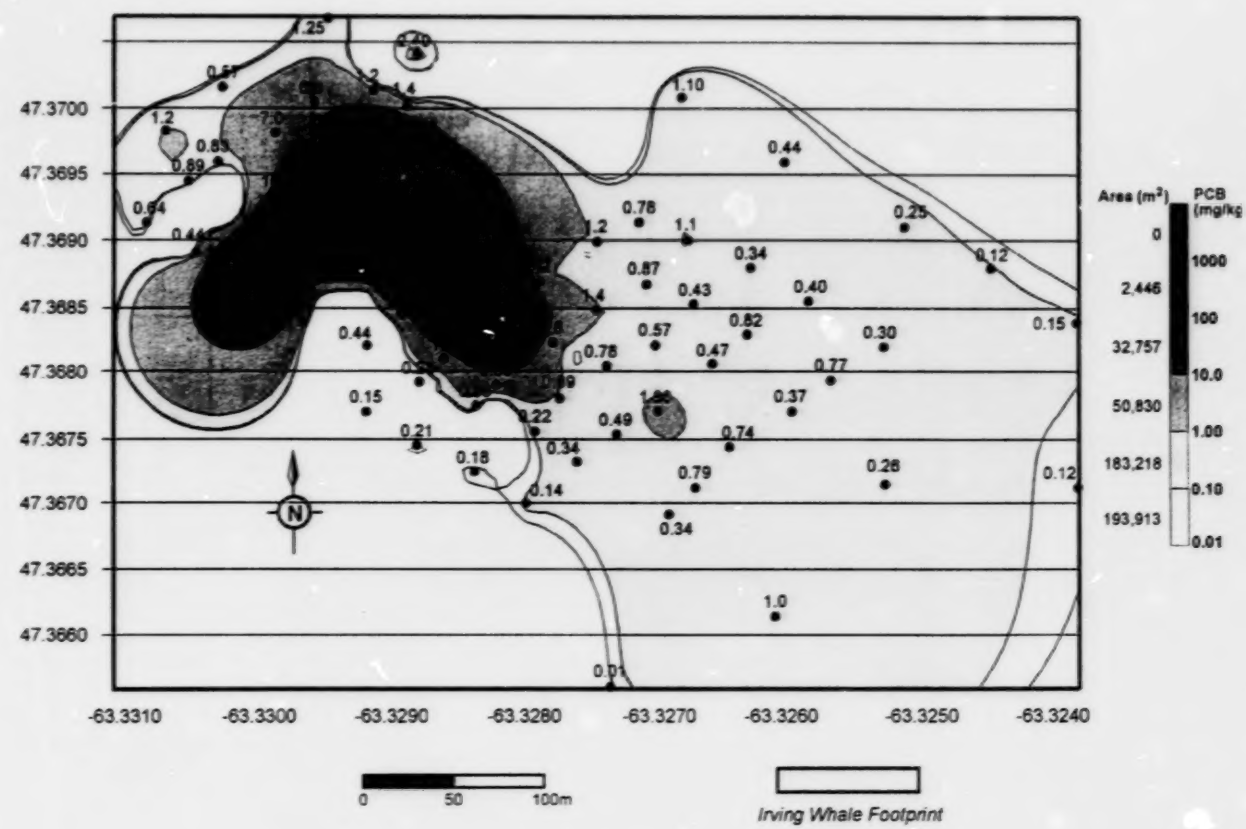


Figure 3. PCB concentrations in sediments at the *Irving Whale* site pre-lift, spring 1996.

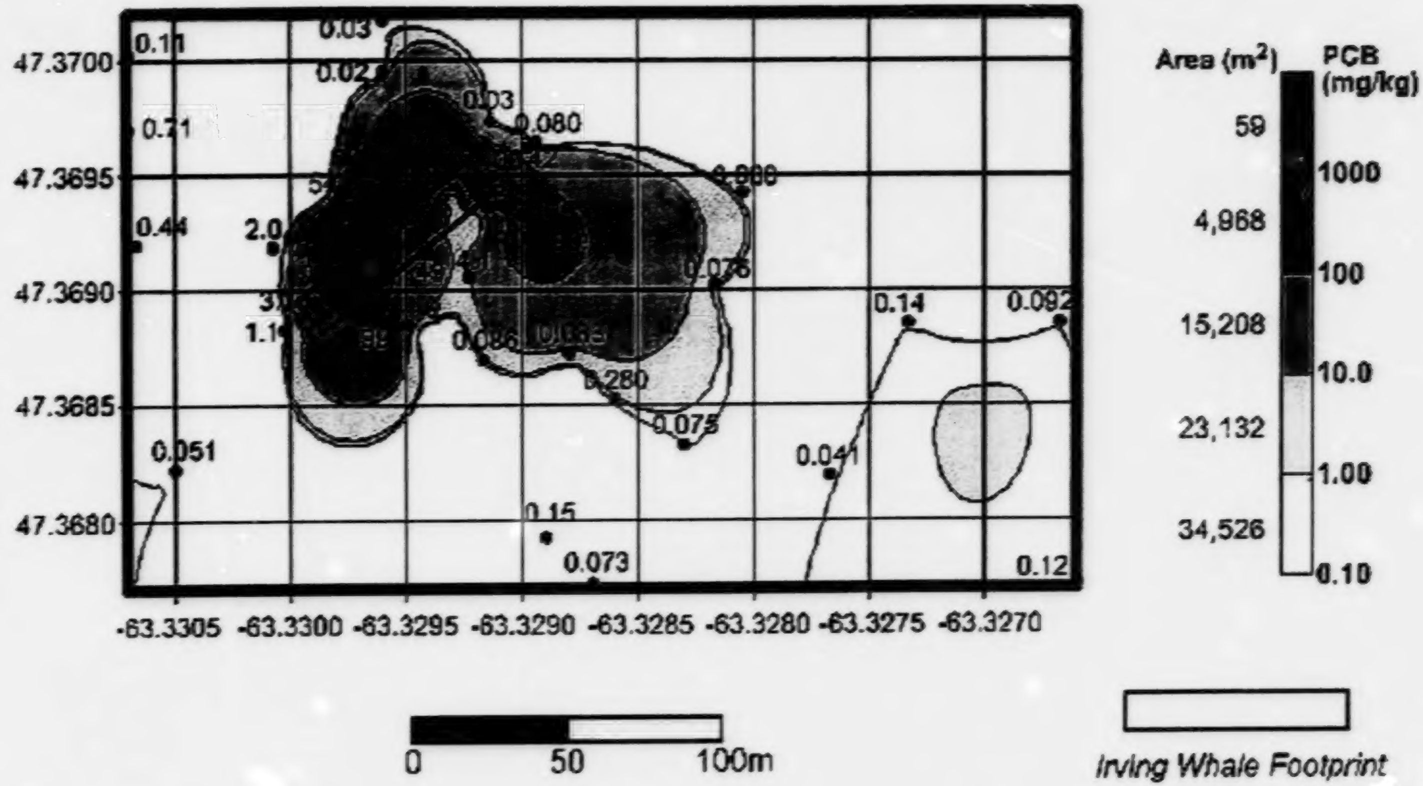


Figure 4. PCB concentrations in sediments at the *Irving Whale* site post-lift, August and October, 1996.

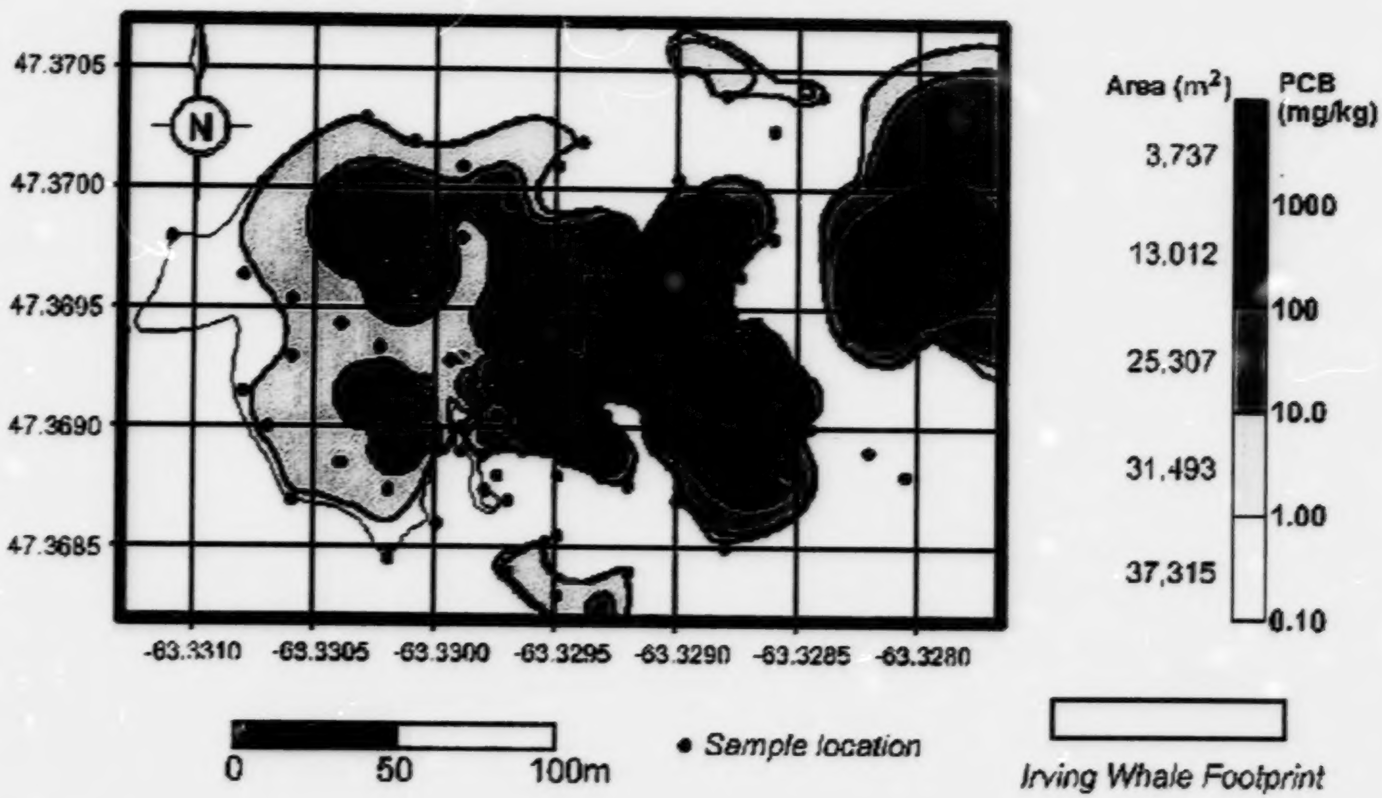


Figure 5. PCB concentrations in sediments at the *Irving Whale,* 1997.

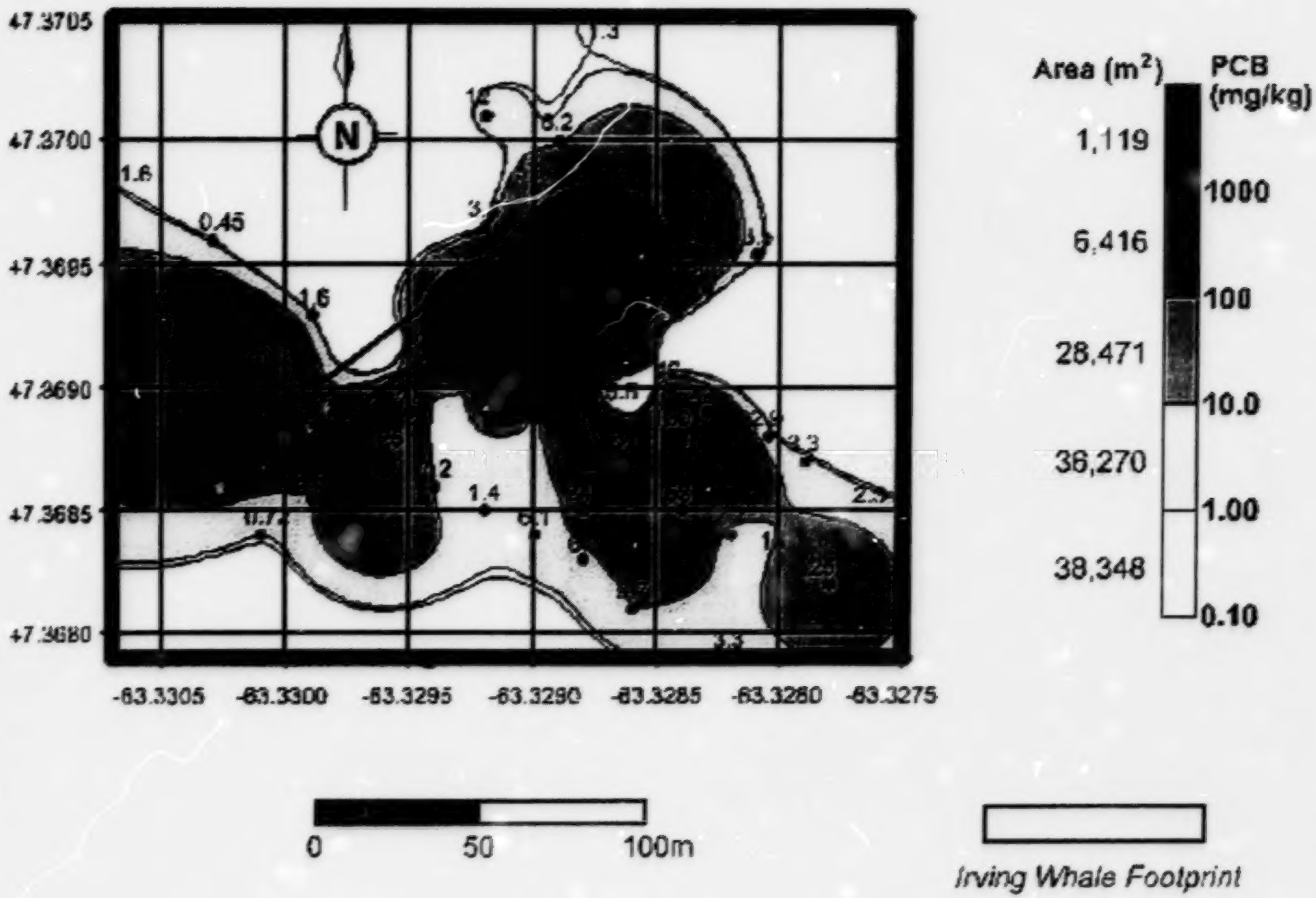


Figure 6. Area Calculations for contour maps of PCBs in sediment at the *Irving Whale* site, 1996 - 1999.

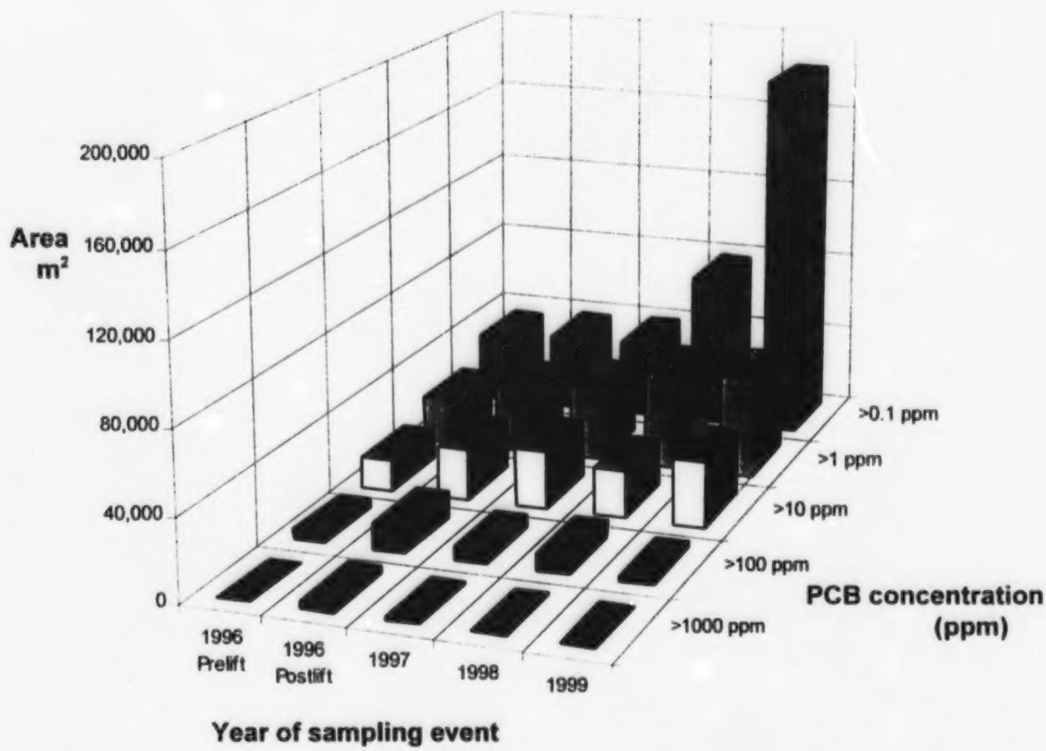
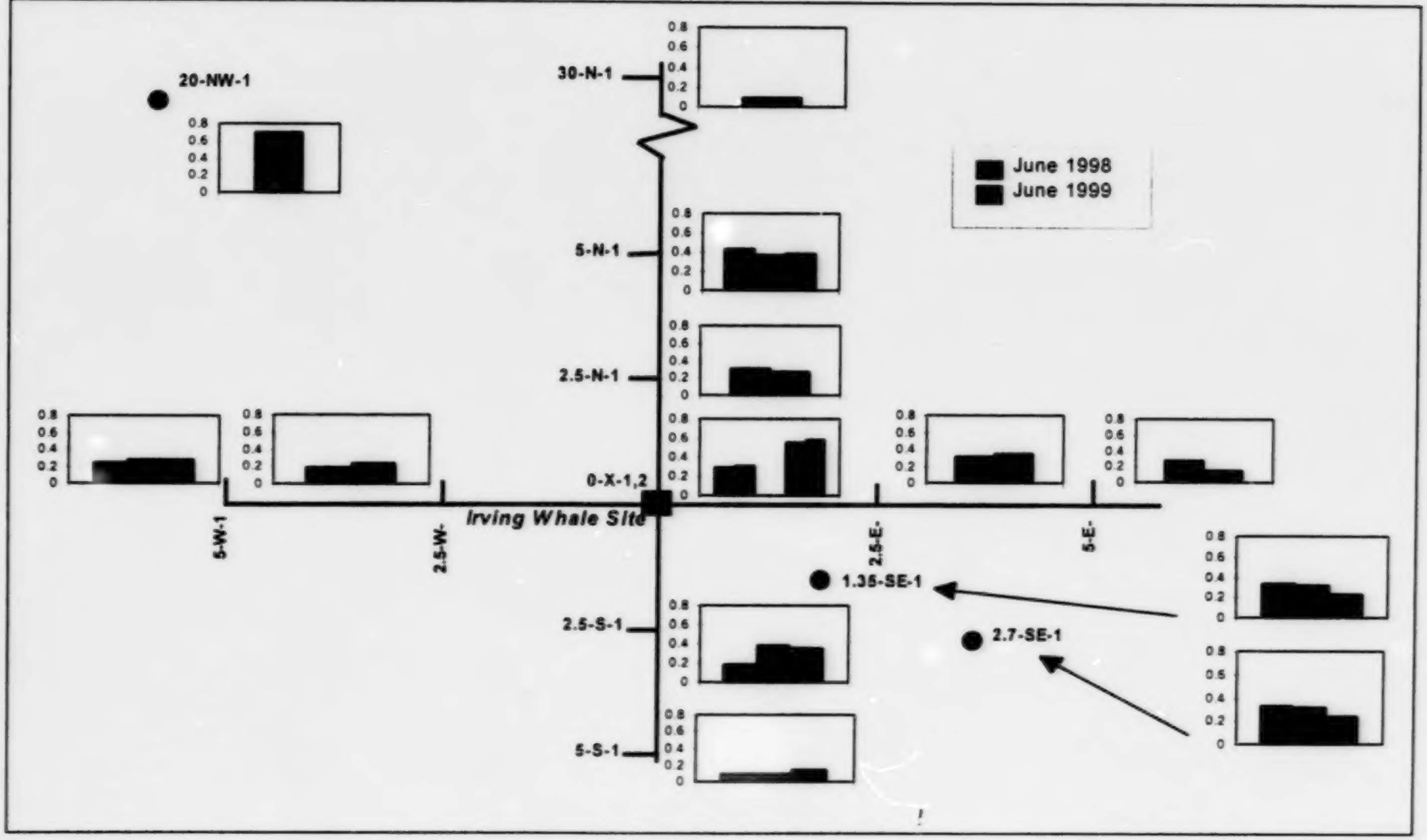


Figure 7. Diagram of the sum of chlorobiphenyl concentrations (μg/g wet wt.) in digestive gland pools from snow crabs in the area of the footprint of the *Irving Whale* barge, captured in June1998 and June 1999. Replicate analysis are shown in adjoining bars and duplicate sampling is shown by separate bars. in the same graph.



*y-axis chlorobiphenyl concentrations (μg/g wet wt.).

Figure 8. Toxicity of 1998 sediment samples on *Vibrio fischeri* related to PCB concentration.

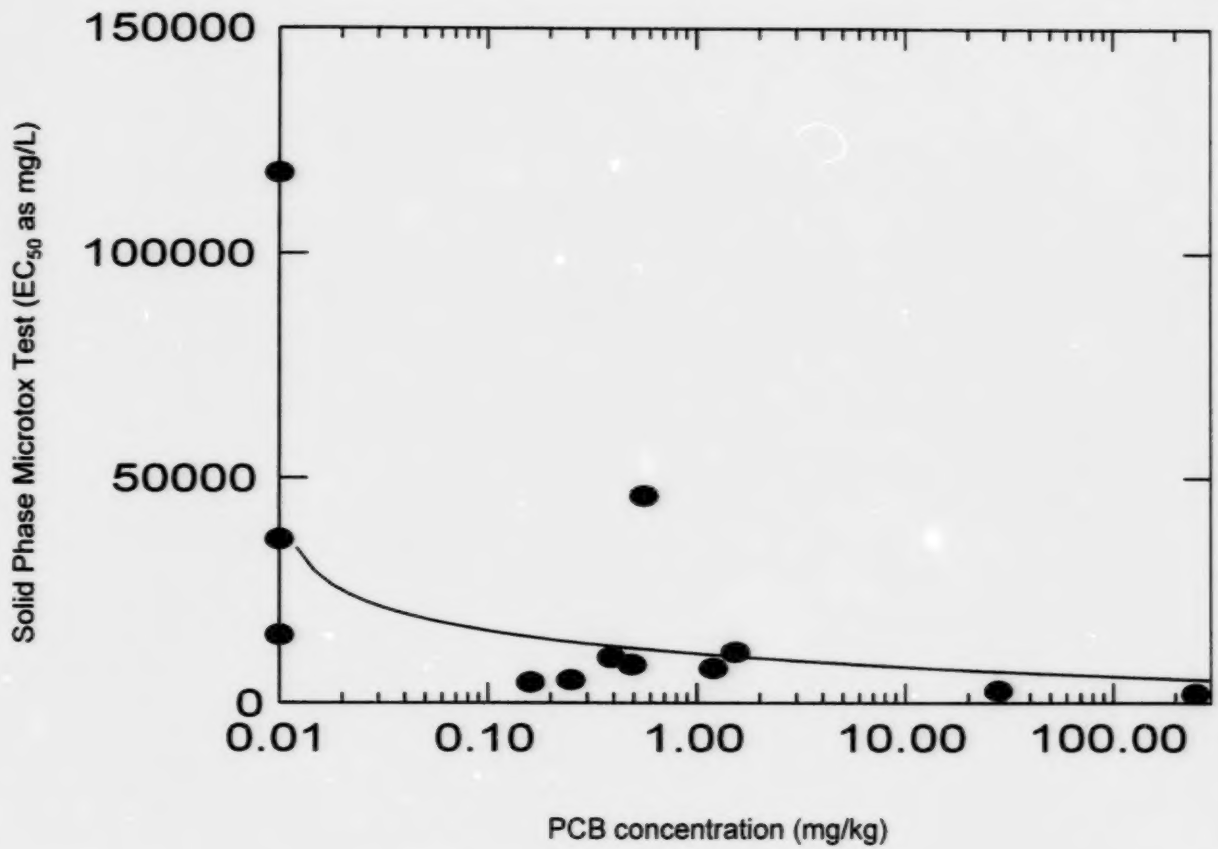


Figure 9. Comparison of cumulative percent frequency at all stations in the vicinity of the *Irving Whale* footprint and at the control site in 1998.

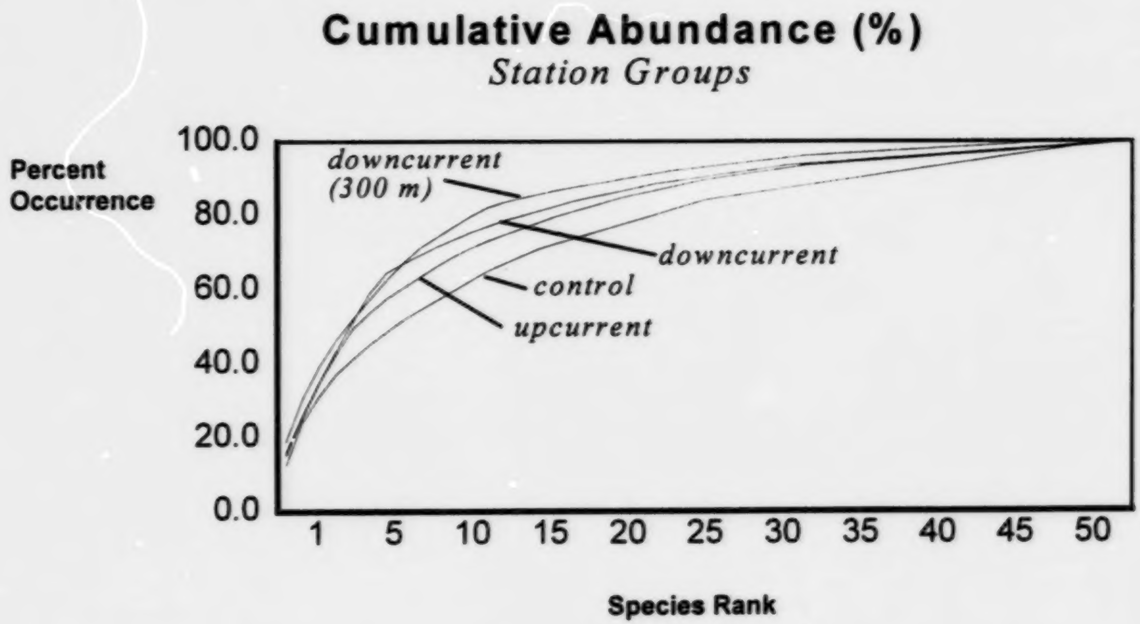


Figure 10. Comparison of geometric size classes at all stations in the vicinity of the *Irving Whale* footprint and at the control site in 1998.

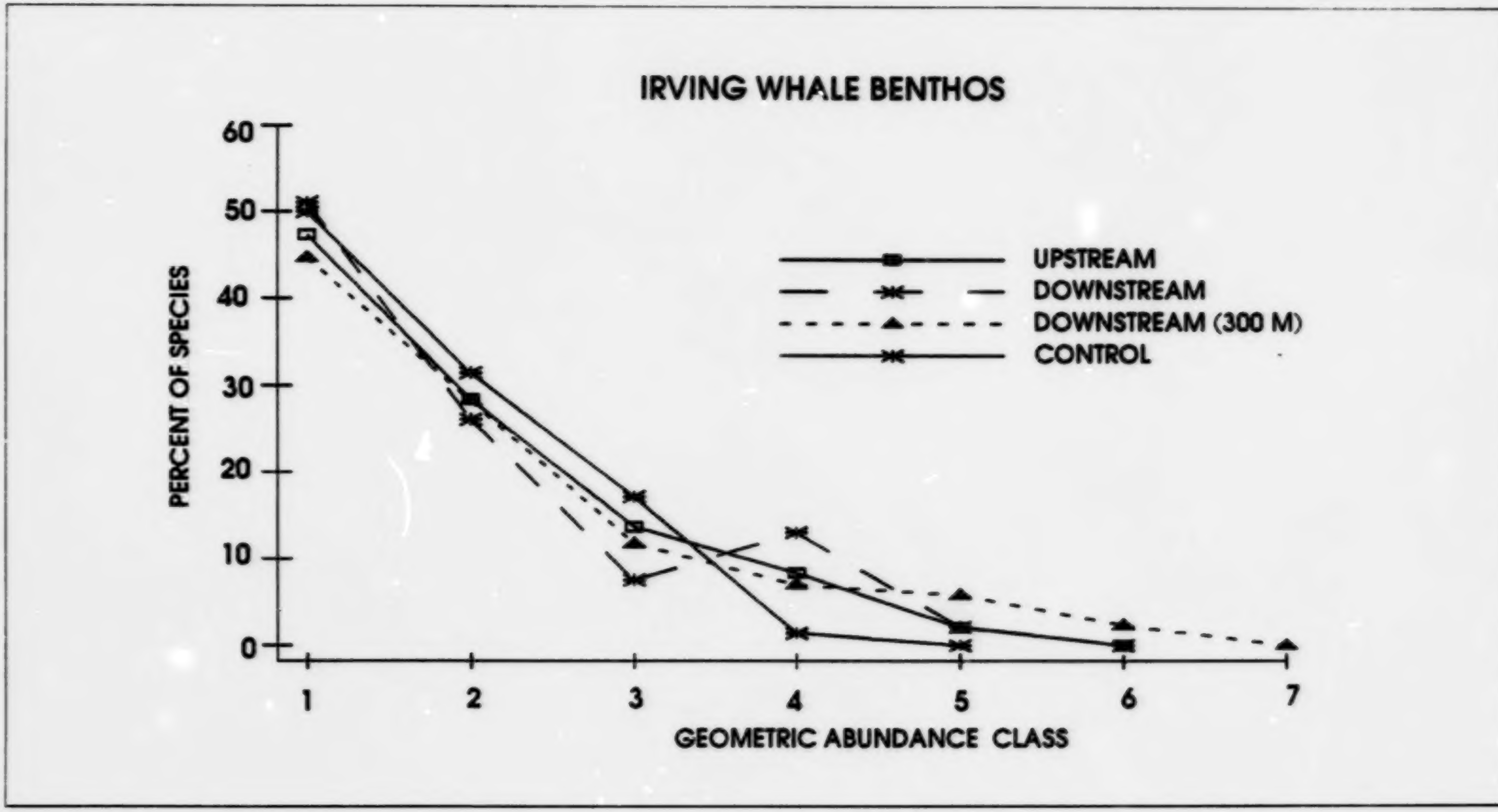


Figure 11. Abundance of polychaetes in terms of total number of species at the *Irving Whale* site versus control and sample locations in 1998.

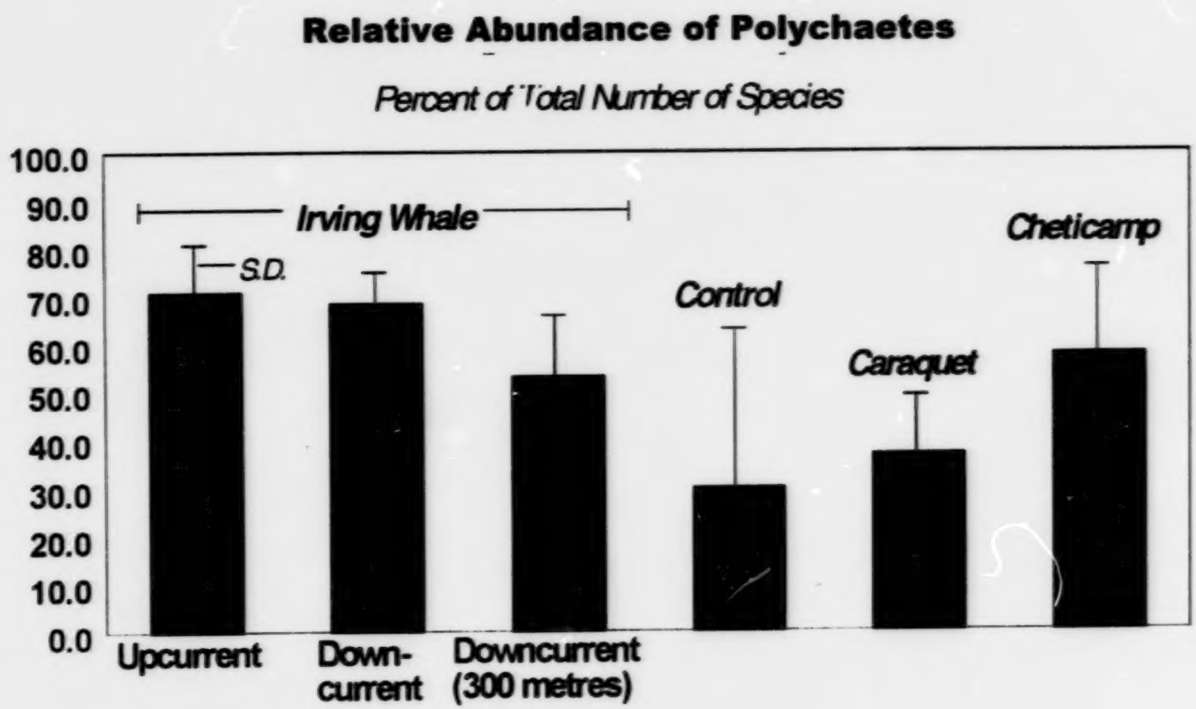


Figure 12. Cluster diagram of similarity of seabed biological communities at the *Irving Whale* and reference sites, based on Czekanowski Index of Similarity.

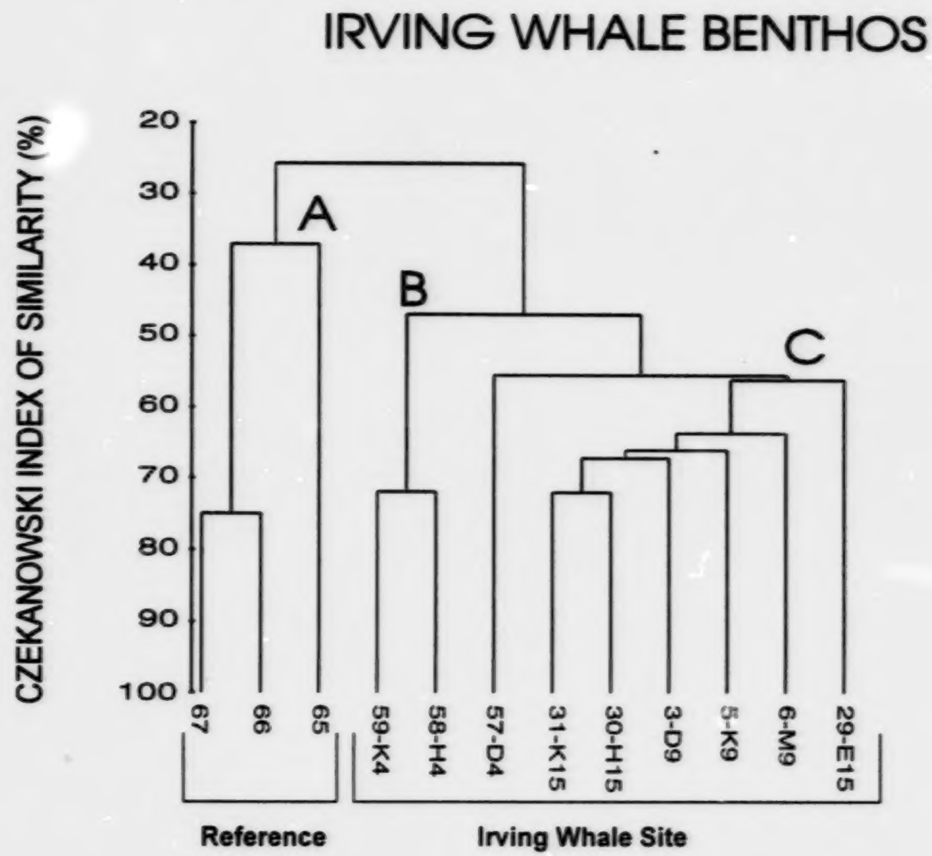
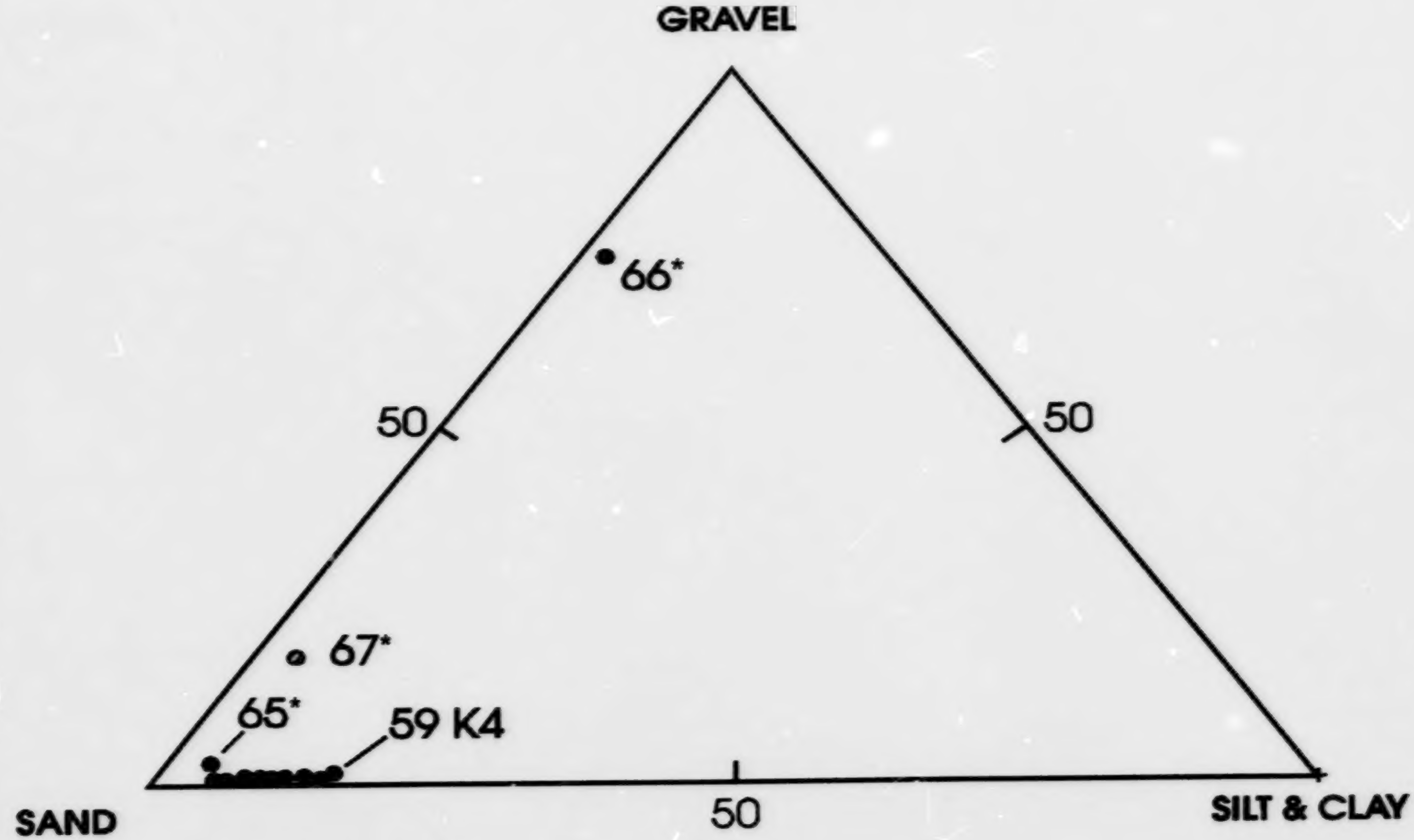


Figure 13. Grouping of 1998 sample stations according to physical characterization of sediments.



* indicates reference locations